

A technique for calculating limb length inequality and epiphyseodesis timing using the multiplier method and a spreadsheet

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Received: 6 December 2006 / Accepted: 30 January 2007 / Published online: 11 April 2007
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Abstract

Purpose Limb length inequality and epiphyseodesis timing calculations are common in pediatric orthopedics. The multiplier method developed by Paley et al. has significantly simplified the calculation of ultimate limb length. The calculation of limb length inequality has also become very simple for congenital limb length inequalities. However, the equations for limb length inequality from acquired differences and epiphyseodesis timing are not simple, and are prone to arithmetic errors.

Methods To limit these errors, we have developed a spreadsheet which finds the appropriate multipliers, solves the equations, and computes the predicted limb length inequality and the appropriate age for an epiphyseodesis.

Results This method of using a spreadsheet and the multiplier calculations is quite simple and quick to use in practice. The calculations can be cut and pasted into computerized charts for future reference.

Conclusions We recommend this method for clinical use and make it available for public use.

Keywords Limb length inequality · Multiplier method · Calculations

Introduction

Limb length inequality and epiphyseodesis timing calculations are common in pediatric orthopedics. The multiplier method developed by Paley et al. [1] has significantly simplified the calculation of ultimate limb length, and calculation of limb length inequality for congenital discrepancies. However, the equations for limb length inequality from acquired differences and epiphyseodesis timing are not simple, and are prone to arithmetic errors. To limit these errors, we have developed a spreadsheet which finds the appropriate multipliers, solves the equations, and indicates the appropriate age for an epiphyseodesis.

The spreadsheet works on desktop spreadsheet programs compatible with Microsoft Excel, and on the current version of Microsoft Pocket Excel for personal digital assistants (PDAs). Because of the ubiquity of spreadsheet programs, including free versions such as Open Office (available from <http://www.openoffice.org/>), this spreadsheet can be used by anyone with a computer. We have it available on computers in our outpatient clinic for resident and staff use. The spreadsheet is available as Supplementary material.

Required user input

The user enters the patient's sex and age and then the direct measurements from the limb-length study. If the discrepancy is not congenital, prior limb-length study measurements are also necessary to calculate the relative growth of the short to the long leg. We use either scanograms or long-leg films with a ruler, and have chosen to have the spreadsheet calculate the lengths rather than perform manual calculations. All of the calculations and predictions are done by the spreadsheet.

Electronic supplementary material The online version of this article (doi:10.1007/s11832-007-0016-6) contains supplementary material, which is available to authorized users.

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The spreadsheet assumes a Shapiro type 1 inequality [2], with the limbs growing proportional to each other. This type of discrepancy includes physal injuries, static differences from fractures, and most of the limb length differences seen clinically. We advise using distant measurements in time to minimize problems from small measurement errors. The spreadsheet also allows a constant fixed difference, such as from a foot height or pelvis deformity, to be added into the calculations.

Instructions

The user enters data into the yellow-colored fields. The user only needs to work from the worksheet titled “Scanograms and Calculations”.

1. Enter the patient’s age as Years+Months into field B2 (years) and C2 (months).
2. Enter the sex as “M” or “F” into B3.
3. Enter the direct readings from the scanograms into fields B5:E7.
4. The correct multiplier will automatically be displayed in E2.
5. If the discrepancy is congenital, then D5:E7 should all be zero.
6. If scanograms are not used in favor of a method providing direct segment length measurements, such as some digital radiographs and most CT scanograms, disregard steps 3 and 4 and enter the segment lengths directly into fields B8:E10 in a similar fashion.
7. The current and prior limb length differences are automatically displayed in orange fields B12 and D12.
8. If there is any additional static difference, enter it as a positive number if it makes the long leg longer, and negative if it makes the long leg shorter, into field B13.
9. The projected length of the long leg and limb length difference at maturity are automatically shown in the dark blue fields of row 15 and the discrepancy in B16.
10. The proper estimated timing for a distal femoral, proximal tibial, or distal femoral and proximal tibial epiphyseodesis to be done in years and months are automatically shown in the light blue fields B18:C20. If the age is younger than the current age, then the patient is too old for that specific epiphyseodesis to suffice.

Calculations (done by the spreadsheet)

The user does not need to do the calculations, but this section describes the methods used by the computer to automatically display the values in the spreadsheet. Once

the age (fields B2 and C2) and sex (field B3) are entered, the computer finds the multiplier by using the VLOOKUP function from the “Multiplier” worksheet. The spreadsheet linearly interpolates the results to the entered age as a decimal entry. In our clinic, the leg lengths for the right and left are directly calculated from the values on the ruler. The length of the long leg at maturity is calculated by multiplying the current long limb length by the multiplier. The length of the short leg at maturity is calculated based upon the relative growth of the short to the long leg and adding the projected growth to the current short limb length. This is similar to the growth inhibition calculations described by Moseley [3, 4].

The computer identifies the timing for epiphyseodesis by calculating the proper multiplier at the time of epiphyseodesis and using the VLOOKUP function and linear interpolation to find the age from either the “Boys” or “Girls” worksheets. The formulas used for calculating the multiplier at epiphyseodesis, and their derivation, are shown in the appendix.

Since the spreadsheet is being provided open source, users can modify it according to their local circumstances. For example, we currently use plain radiographic scanograms and long leg standing films with a ruler. The direct ruler measurements are placed in the appropriate fields B5:E7. However, if a user has a computerized radiology system, which obtains direct measurements of the tibias and femurs, those measurements can be placed directly into fields B9:E10 rows 5–7 being removed.

The spreadsheet also has an additional field (B13) to enter any otherwise unaccounted estimated discrepancy at maturity, such as from a pelvic osteotomy or foot deformity. A positive value increases the final limb length difference, while a negative value decreases the final limb length difference to calculate epiphyseodesis timing.

An example

A 10-year, 4-month-old boy presents with a limb length inequality from a proximal tibial injury at age 4. He had scanograms at age 7 and again at age 10 years, 4 months.

The scanograms readings are shown in Table 1 below.

Note that the ruler was placed in different directions for the two separate measurements.

Going to the spreadsheet, the age 10 years 4 months is entered in fields B2 and C2, and the sex, “M”, is placed in cell B3. The scanogram readings are then placed in the appropriate fields B5:E7. The spreadsheet looks up the published multipliers and linearly interpolates a more precise multiplier. The interpolation is done in the “Interpolation Calculations” worksheet.

Table 1 Scanogram measurements at ages 7 and 10 + 4 on a 10 year, 4 month old boy with a proximal tibial physeal injury at age 4 years

	Age 10		Age 7	
	Right	Left	Right	Left
Hip	70.6	66.9	5	8
Knee	34	31.5	35.2	37.5
Ankle	5	4.8	58	58

The spreadsheet then calculates the current and previous discrepancies, length of the long and short legs at maturity, the predicted discrepancy, and the appropriate ages for various epiphyseodesis. The interpolation calculations for epiphyseodesis timing are in the “Interpolation Calculations” worksheet. If there were any additional estimated discrepancy, it would be placed in field B13.

In this example, the current limb length difference (LLD) is 3.5 cm and the previous one was 3 cm. The projected difference is 4.3 cm. The proper timing for a distal femoral epiphyseodesis is at age 12 + 9, a proximal tibial epiphy-

seodesis at age 10 + 8, and both at age 13 + 10. These calculations are obviously more precise than reality but do provide good estimates for timing (See Fig. 1).

Effects of magnification

Scanograms and CT scanograms avoid the problem of film magnification, since they do not have radiographic parallax. Full-length films with a ruler have this potential problem. Machen and Stevens [5] reported that because always using full-length films results in consistency despite magnification, it is reasonable to use full-length films routinely rather than scanograms. However, Sabharwal et al. [6], while agreeing with this conclusion for differences under 2 cm, noted that larger differences are magnified on average 4.6% on the full-length films. Because the multiplier method works upon proportions rather than absolute lengths, the calculations for epiphyseodesis timing do not change, although the absolute limb length differences will change.

	A	B	C	D	E
1		Years	Months	Age (decimal)	Multiplier*
2	Age:	10	4	10.33	1.30
3	Sex (M or F):	m			
4	Scanogram:	Right Current	Left Current	Right Prior	Left Prior
5	Hip	70.6	66.9	5	8
6	Knee	34	31.5	35.2	37.5
7	Ankle	5	4.8	58	58
8	Lengths:	Right	Left	Right	Left
9	Femur	36.6	35.4	30.2	29.5
10	Tibia	29	26.7	22.8	20.5
11	Femur + Tibia	65.6	62.1	53	50
12	LLD (cm)	3.5		3	
13	Additional difference	0			
14	Projected Length of Long Leg (cm)	Projected Long Leg with Additional Difference (cm)	Projected Length of Short Leg (cm)	%growth rate of short	Growth inhibition
15	85.3	85.3	81.0	96.0%	4.0%
16	Projected discrepancy	4.3			
17	Predicted age for LLD=0:	years	months		
18	Distal Femoral Epiphyseodesis	12	9		
19	Proximal Tibial Epiphyseodesis	10	8		
20	Distal Femoral and Proximal Tibial Epiphyseodesis	13	10		
21	* All values come from Paley D, Bhavre A, Herzenberg JE, et al. Multiplier method for predicting limb-length discrepancy. J Bone Joint Surg Am. 2000;82-A:1432-1446.				
22	Enter age in years and months in B2 and C2. Enter Sex as M or F in B3. Enter measurements in B5-E7 (leave D5-E7 zero for congenital differences). Enter any otherwise unaccounted discrepancy in B13.				
23	Scanograms and Calculations / Multipliers / Boys / Girls / Interpolation Calculations				

Fig. 1 The figure demonstrates the spreadsheet with entries from the example in the text

Summary

We have found this method of using a spreadsheet and the multiplier calculations quite simple and quick to use in practice. The calculations can be cut and pasted into our computerized chart for future reference. We make this available to all users and welcome suggestions or improvements.

Appendix

For the following solution to the equations:

Lc	Current length of long leg
Mc	Current multiplier
R	Rate of short to long leg growth
Sc	Current length of short leg
Sp	Prior length of short leg
Lc	Current length of long leg
Lp	Prior length of long leg
Gs	Growth remaining of short leg
G _L	Growth remaining of long leg
Sm	Length of short leg at maturity
Lm	Length of long leg at maturity
Fe	Femoral length at epiphyseodesis
Te	Tibial length at epiphyseodesis
Me	Multiplier at epiphyseodesis
Dm	Any additional length discrepancy at maturity beyond the femur and tibia

Solutions to the equations

Long leg length at maturity = $LcMc$

Rate of growth of short leg compared to long leg = $R = (Sc - Sp)/(Lc - Lp)$

Length of short leg at maturity = $Sc + Gs$, where Gs = growth remaining of short leg.

$Gs = RG_L$ where G_L = growth remaining of long leg = $Lm - Lc = McLc - Lc = (Mc - 1)Lc$

Therefore, $Sm = (Lm - Lc)R + Sc$

If no epiphyseodesis is done:

$$Lm = McTc + McFc$$

If a distal femoral epiphyseodesis is done, the femur grows at 29% of its normal rate:

$$\begin{aligned} Lm &= McTc + [0.29(Mc - 1) + 1]Fc \\ &= McTc + (0.29Mc + 0.71)Fc \end{aligned}$$

If a proximal tibial epiphyseodesis is done, the tibia grows at 46% of its normal rate:

$$\begin{aligned} Lm &= [0.46(Mc - 1) + 1]Tc + McFc \\ &= (0.46Mc + 0.54)Tc + McFc \end{aligned}$$

Similarly, if both proximal tibial and distal femoral epiphyseodesis are done:

$$Lm = (0.46Mc + 0.54)Tc + (0.29Mc + 0.71)Fc$$

Timing for epiphyseodesis

For a distal femoral epiphyseodesis and $LLD = 0$

$$Lm - Sm = 0$$

Using the prior equations and substituting Sm for Lm

$$\begin{aligned} Sm &= MeTe + (0.29Me + 0.71)Fe \\ &= MeTe + 0.29MeFe + 0.71Fe \end{aligned}$$

But, $MeTe = Tm = McTc$, and $MeFe = Fm = McFc$, and $Fe = Fm/Me = McFc/Me$

Solving this gives:

$$Me = 0.71McFc/(Sm - McTc - 0.29FcMc)$$

If you wished to account for an additional difference at maturity, the equation would solve to:

$$Me = 0.71McFc/(Sm - McTc - 0.29FcMc - Dm)$$

Similarly, for tibial epiphyseodesis:

$$Me = 0.54McTc/(Sm - 0.46McTc - McFc - Dm)$$

Or for both tibia and femur:

$$\begin{aligned} Me &= (0.54Tc + 0.71Fc)Mc/(Sm - 0.46TcMc \\ &\quad - 0.29McFc - Dm) \end{aligned}$$

Another way of deriving the same equations is using growth inhibition, which many users may find simpler to follow. This uses the equation:

Growth inhibition $I = (\text{rate of growth of long-rate of growth of short})/(\text{rate of growth of long})$.

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